LDMOS Technology for 5 GHz Power Amplifiers

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We show today's capability of LDMOS technology for 5 GHz power amplifiers. The most important RF parameters: efficiency, gain, and output power, are presented for frequencies from 1 up to 12 GHz and we explain the pros and cons of the several LDMOS nodes (12V, 30V, 50V). To show the intrinsic LDMOS performance we use on wafer load pull measurements for small structures in ground-signal-ground configuration. Spectacularly high RF performance is measured for 6W devices made in LDMOS 30V node: at 12 GHz, we measure a 35% drain efficiency, in combination with 10 dB gain and 1.0 W/mm power density. Furthermore at 5 GHz, this on wafer LDMOS has about 63% drain efficiency, 19 dB gain and 1.4 W/mm, showing that LDMOS can serve 5 GHz applications. As a product demonstrator, we show the first packaged C-band LDMOS amplifier with more than 20W output power and an efficiency of 50-51% over the band in combination with 15-16 dB maximum linear gain.

LDMOS (laterally diffused metal-oxide-semiconductor) transistors were more than twenty years ago introduced in the RF power market as a replacement of bipolar transistors for base station applications. During the last decades, LDMOS technology has spectacularly evolved [1] and is nowadays the leading technology for a wide variety of RF power applications, to mention a few: base station, broadcast, FM, VHF, UHF, industrial, scientific, medical, and radar. Steadily the LDMOS frequency range of operation has expanded upwards up to 4 GHz, including Wimax and S-band radar frequencies [2]. The next application area will be the 5 GHz frequency range for C-band radar and the future 5G Base station bands. In this presentation, we show the capability of LDMOS technology for these 5 GHz applications and explore LDMOS even up to 12 GHz.

We present RF measurements for on wafer Ground-Signal-Ground structures with power levels of 5-10W, fabricated in the various Ampleon's LDMOS technology nodes (12V, 30V and 50V), conducted with a state-of-the-art active load pull setup [3]. The setup maximum frequency is 18 GHz and it allows control of the in- and output impedances up to the third harmonic. We force class (A)B operation of the LDMOS by shorting the output harmonics and adjusting the quiescent current for flat linear gain.

The frequency roll-off of the efficiency is plotted and this roll-off can nicely be described with a simple equivalent circuit loss model [1]. The class (A)B efficiency is 72% at low frequency, which is slightly below the theoretical maximum of 78.5% due to on-resistance losses caused by the drain extension in the LDMOS device.

The LDMOS efficiency can be further boosted by optimizing the harmonic terminations, especially the output impedance terminations. Optimizing only the second harmonic output impedance termination, results in more than 80% peak efficiency at 2.14 GHz, which is about 10% efficiency increase compared to the class AB efficiency. This efficiency enhancement becomes gradually less as the frequency is increased: around 5 GHz we see only a few percent efficiency enhancement.

For higher frequencies, the efficiency is reduced due to output capacitance losses. The efficiency is 63% at 5 GHz and around 35% at 12 GHz, spectacularly high values for a Si based power technology. The power density is around 1.6 W/mm at low frequency and is limited by the supply voltage sweep and the maximum current. At 12 GHz, the power density is still around 1 W/mm. Finally, the frequency roll-off of the power gain is well described by a 6 dB/octave behaviour. The gain is 19 dB at 5 GHz and 10 dB at 12 GHz for this LDMOS. The 0dB frequency is around 30 GHz, which is much higher than the 16 GHz cut-off frequency due to additional voltage/impedance amplification.

As a next step to explore LDMOS capabilities at 5 GHz frequencies, we have built a C-band demo BLCF9G4650L(S)-20 tuned for the frequency band 4.6-5.0 GHz to show that LDMOS fully meets all requirements. In this demo circuit, LDMOS shows 50-51% efficiency in 3dB compression and 15-16dB maximum linear gain over the frequency range 4.6-5.0 GHz. If we compare this broadband performance to GaN application datasheet performance numbers [4], we see that LDMOS has a similar efficiency and gain as the best in class GaN providers. This good RF performance [5] in combination with the proven reliability record shows the capabilities of LDMOS at 5 GHz frequencies, both for C band radar applications and for future 5G Base Station bands.

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